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ARMY MEDICAL RESEARCH LABORATORY

FORT KNOX, KENTUCKY

REPORT NO. 117

18 June 1953

THE ACCURACY OF THROWING HAND GRENADES
AS A FUNCTION OF THEIR WEIGHT, SHAPE AND SIZE*

*Subtask under Human Engineering Studies, AMRL Project No. 6-95-20-001, Subtask, Field Test Studies.
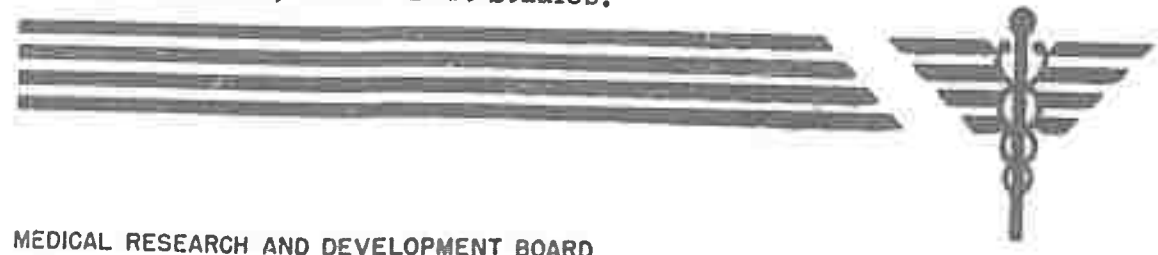
MEDICAL RESEARCH AND DEVELOPMENT BOARD
OFFICE OF THE SURGEON GENERAL
DEPARTMENT OF THE ARMY

REPORT NO. 117

THE ACCURACY OF THROWING HAND GRENADES
AS A FUNCTION OF THEIR WEIGHT, SHAPE AND SIZE*

by

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from

ARMY MEDICAL RESEARCH LABORATORY
FORT KNOX, KENTUCKY
18 June 1953

Report No. 117
Project No. 6-95-20-001
Subtask AMRL S-5
MEDEA

ABSTRACT

THE ACCURACY OF THROWING HAND GRENADES
AS A FUNCTION OF THEIR WEIGHT, SHAPE AND SIZE

OBJECT

This study involved the investigation of the influence of the shape, weight and size upon the accuracy and consistency with which hand grenades were thrown. Four shapes, three weights and three sizes were used. The grenades were thrown at a target which was 30 yards from the thrower.

RESULTS

Each increase in weight resulted in a decrement in the accuracy with which the grenades were thrown. Performance with the middle weight (18 ounces) was the most consistent. The sphere was significantly poorer in accuracy than the other shapes. No significant changes in performance associated with size were found for the conditions used in the present study.

CONCLUSIONS

Both accuracy and consistency changed as weight was altered. In terms of consistency, there was an optimum weight, above and below which performance was poorer. The range of sizes used in this study was not sufficient to demonstrate significant changes in performance.

RECOMMENDATIONS

1. The present Army hand grenade should be redesigned as a lighter object, probably weighing in the vicinity of eighteen ounces.

2. The present shape should not be altered, pending further study.

3. The present size should not be altered, pending further study.

4. Additional stuides using greater scoring precision should be done in order to determine more accurate interactions of size, shape and weight.

Prepared by:

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    J. T. Burke, Capt, Armor
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THE ACCURACY OF THROWING HAND GRENADES
AS A FUNCTION OF THEIR WEIGHT, SHAPE AND SIZE

I. INTRODUCTION

The hand grenade is one of the Army's close-combat weapons. Its effectiveness is determined by many factors, among which the physical characteristics of the grenade and the conditions under which it is thrown should be included. Throwing a grenade is a type of gross psychomotor task requiring a large amount of force and a lesser amount of fine control (coordination) and skill. Variables, such as size, weight, shape and surface, can alter the effectiveness of the throw. There are no published reports of experiments concerning the manner in which these physical variables affect performance at this level of gross psychomotor performance.

A pilot study was run to determine the most feasible experimental procedures and analytical techniques. Sample experimental shapes were thrown at targets located at several distances. From the results of the pilot study, a throwing distance of 30 yards was selected for the present study. This distance was chosen for the following practical reasons. It appears that this is the maximum distance which the average soldier can throw a grenade with accuracy; and it is a useful distance in a tactical sense in that it is an "optimal" distance in terms of maximum effectiveness and minimum proximity to the enemy.

Three physical characteristics of grenades were chosen for study in this investigation. The variables under study were weight (12, 18 and 24 ounces), shape (sphere, standard, tear drop and potato masher), and size (2, 2 1/4 and 2 1/2 inches of diameter). The grenades were thrown at a horizontal, bull's-eye type of target located at the selected distance (30 yards) from the subject.

A factorial design was used in this study; all three variables were studied simultaneously. This technique minimizes time and the number of subjects, and allows the experimenter to investigate both the primary effects of the variables and their interactions. For a design of this type, analysis of variance is the appropriate statistical tool.

Both accuracy (radial distance from the target center) and consistency (dispersion, or the scatter of the throws) were used as measures of performance.

II.   EXPERIMENTAL PROCEDURE

A.   Grenades

Thirty-six grenade types were designed and produced in cast aluminum. Five grenades of each type were made. The 36 types were determined by taking all combinations of the weights, shapes and sizes previously selected. The types are shown in Table 1. The grenade shapes and dimensions are shown in Figures 1 and 2. Appropriate weights were obtained by removing aluminum and adding lead where necessary. The weights actually obtained were within one ounce of the desired weight, with two exceptions. All five of the #28 grenades weighed 15 ounces instead of the specified 12 ounces. One of the #10 grenades weighed 22 ounces instead of the specified 24 ounces. These errors were not discovered until after the data had been collected.

B.   Targets

The target arrangement is shown in Figure 3. This was a horizontal, bull's-eye-type target, with a series of concentric circles and reference pins placed to aid in scoring. Three targets were laid out on a flat piece of ground, each 30 yards distant from the thrower. The barricade indicated in Figure 3 was 4 feet high and 5 feet wide. The thrower was required to crouch behind the barricade between throws. Throwing was done from a standing position. The barricade thus prevented a constant view of the target, kept the thrower at the required distance, and insured that all throws would be made overhand. There was a slight upward slope between the throwers and the targets, but no differences in elevation within the target areas.

C.   Subjects

Twenty-five subjects from a line battalion at Fort Knox were employed as throwers. The subjects were required to be men in good health, with no physical deformities of their throwing arms or hands, and were a random sample from the unit. These 25 subjects were drawn from a pool of over 500 men. None had previously served in an experiment of this type, and all were several months past their basic training. Two subjects dropped out during the experiment, leaving scores for 23 subjects for the statistical analyses.

D.   Throwing

All subjects were required to make five throws with each type of grenade, for a total of 180 throws per subject. To avoid

undue fatigue, subjects threw 30 times (6 different types of grenades), approximately every other day. All 5 grenades of a specific type were thrown in succession. The six different types were thrown in succession in a predetermined order. Each session lasted approximately 20 minutes. Subjects threw in groups of three, each at a separate target, and each with a different group of 6 grenade types. The order of throwing was systematically balanced between subjects and no two subjects threw in the same order. While these precautions reduced differential practice effects and fatigue effects, it should be remembered that this task required a large amount of gross strength.

E. Scoring

All throws were recorded in terms of distance to the nearest yard from the bull's-eye and in terms of direction to the nearest hour of clock time, with the 12 o'clock position coinciding with the line from the subject to the bull's-eye (Figure 3). A center hit was recorded as zero in distance and direction. The score was taken at the initial point of contact, with the roll of the grenade disregarded. A sample score is given in Figure 3.

III. RESULTS

A total of 4140 scores were obtained, five for each of 23 subjects on each of the 36 grenades. A mean was calculated for each group of five throws, giving 23 means (one for each subject) on each grenade. These means were then summarized into a single mean for each grenade. Two kinds of means could be calculated from the scores:

1. The absolute value of the radial error scores without considering the direction could be summed and a mean obtained from this sum. This mean represented the radius of a circle concentric to the target center, and gave no information about direction from the target center. It can be represented by the following sketch.
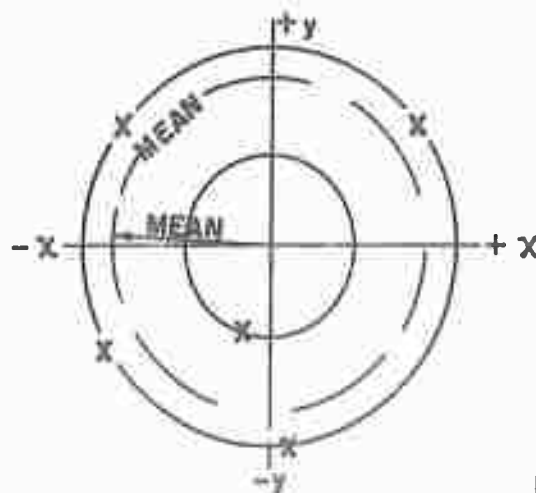
2. The exact point of contact of the grenade upon the target as it was laid out on the ground could be described by the distance and direction score which was recorded for the throw. This geographical point could be converted into X and Y coordinates (zero for both scales being the bull's-eye). A mean X and a mean Y could be obtained separately for a group of throws and these means could be combined into a single score.* It can be represented by the following sketch.
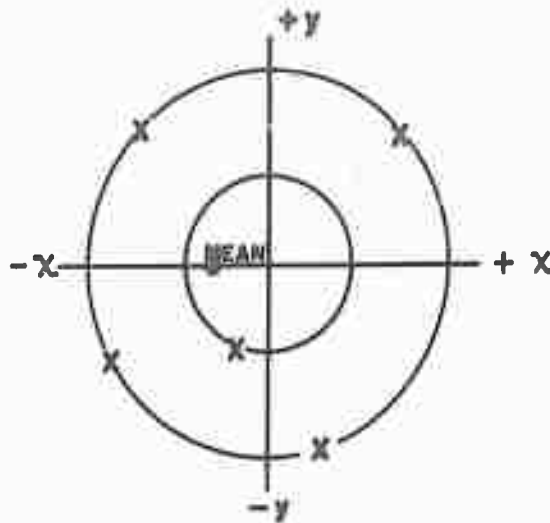
The two sketches of the same distribution of throws demonstrate that the two methods of calculating means yield quite different values, and that the first method gave a value which could not be defined by a point in space. Furthermore, the mean obtained by the first method precluded predicting the point of contact of a future throw. Consequently, trigonometric means used in the second method were selected as the more desirable.

Examination of the frequency distributions of the raw scores and of the means of each group of five throws revealed marked skewedness. This skewedness arose from two sources. First, the target was at a distance which required that the subjects throw with very nearly their maximum strength. As a result, considerably less than half the throws were beyond the target (or on the minus side of the distribution scale). The scores from the pilot study which included a shorter range, suggested that the subjects consistently underestimated the range, further reducing the proportion of throws on

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*See Appendix I.

the minus side of the distribution scale. Second, there seemed to be no way of holding the scores beyond the bull's-eye separate from those short of the bull's-eye. Systems of plus and minus scores, or weighting systems, led to as many difficulties as considering only the absolute value of the scores. Unfortunately, considering only the absolute value meant that the scores beyond were turned back onto the scores short of the bull's-eye, increasing the skewedness of the distribution.

The skewedness and kurtosis seemed to indicate that only non-parametric methods of analysis could be used. However, when the trigonometric means for each subject were further summarized into a single mean for each grenade, all means were short of the bull's-eye, so that skewedness arising from consideration of the absolute value of the scores was not present. The frequency distribution of these 36 means was examined graphically, and the distributions did not appear to deviate from normal (see Fig. 4). These means are the radial distance (error) from the mean point of contact to the bull's-eye for all throws of each grenade.

In addition to the means (which are a measure of accuracy for each of the grenades), average deviations were obtained trigonometrically. These deviation scores are a measure of the variability of a group of throws around the mean for the group. The average deviation instead of standard deviation was selected as the measure of consistency in order to minimize the influence of the high error scores of one of the 23 subjects. The question of consistency is of major importance in selecting the combination of physical characteristics which yield optimal performance. A grenade which has a pattern of throws with a scatter all about the target but whose mean score is exactly on the target probably is not as good a grenade as one which has a pattern of throws having a very small scatter and a mean close to, but not on, the target. With this latter grenade, the chances are better that any single throw will be close enough to the "enemy" to cause damage. The distribution of these deviation scores is also shown in Figure 4.

The mean error scores and average deviations for each of the grenades are presented in Table 2. These scores were subjected to analysis.

The mean error scores for the 36 grenades were plotted on a view of the target (Figure 5). These scores were then summarized in 3 ways as shown in Figures 6, 7 and 8. Figure 6 presents a plot of the scores for each of the shapes, disregarding size and weight. Figure 7 presents a plot of the scores of each of the weights,

disregarding size and shape. Figure 8 presents a plot of the scores for each of the sizes, disregarding shape and weight. It can be seen from Figure 6 that the sphere showed the most marked scatter of scores and that the standard had the most compact scatter. Figure 7 shows that with each increase in weight the cluster of means moved approximately a yard farther out from the bull's-eye, the 12-ounce grenade being most accurate and the 24-ounce grenade being least accurate. Size shows little difference and Figure 8 suggests only that the 2-inch grenades scattered more than did the other two sizes. It should be noted that the same 36 scores were plotted in 4 ways in Figures 5, 6, 7 and 8.

The two sets of scores (mean error and average deviations) appeared to be sufficiently normal to subject them to analyses of variance. A special type of analysis of variance design, called "triple classification--one score per cell,"* is available for the analysis of sets of scores such as were obtained. In this analysis, variability within each cell of the matrix of scores is eliminated, the subjects contributing their own individual variability only to the extent to which the obtained mean differs from a "true" mean of a more general population of throwers. This design does not allow an over-all test for significance in the matrix of scores, but does allow all of the sub-tests for significance. The results are presented in Table 3.

Table 3 shows that weight was a significant variable for both accuracy (at the 1% level) and consistency (at the 5% level), and that shape was significant for accuracy (at the 5% level). Bartlett's tests for homogeneity of variance within the significant F's yielded non-significant Chi-squares. It can be concluded from these Chi-squares that it was the means, and not the variances, which differed significantly. The significance of the differences between the means of each of the steps of shape and weight were tested by the use of "t" tests. The resulting "t's" and their significance levels are presented in Table 4. In terms of accuracy, each of the three weights differed significantly from the other weights. Examination of the mean error scores (accuracy) for the three weights shows that the 12-ounce grenades were most accurate, and the 24-ounce grenades least accurate. In terms of consistency, the 18-ounce grenade differed significantly from the 24-ounce grenade, but not from the 12-ounce grenade. The other two did not differ from each other at

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*The formulas and sequence of F tests for this special analysis of variance were presented by Dr. R. J. Wherry in a graduate seminar at Ohio State University.

a significant level. The obtained "t's" for differences in means for the four shapes shows that the sphere differed significantly from the other three shapes, but that none of the other three shapes differed from each other at a significant level. Examination of the means shows that the sphere was significantly less accurate than the other three shapes. Although significant F's were not obtained from the analyses of variance for size either in accuracy or consistency scores, and for shape in consistency scores, "t's" were calculated. None were significant, a finding consistent with the analysis of variance.

IV. DISCUSSION AND CONCLUSIONS

It appears, from the results of the analyses, that weight showed the most pronounced effects upon performance of the three variables under study. In terms of accuracy, each increase in weight in the series of steps used resulted in increased error scores. The overall mean for the 24-ounce grenades clearly showed that this weight was too great. This was also true for the consistency scores. The 12-ounce grenades were the most accurate, although they were somewhat less consistent than the 18-ounce (not at a significant level, however). The 18-ounce grenades were significantly less accurate than the 12-ounce, but more consistent. It appears that this conflict occurred because the target was located at very nearly the maximum effective range for the average thrower. Possibly, with the use of shorter ranges, the two weights might no longer differ significantly in accuracy. Furthermore, the Army is confronted with the problem of packing a sufficiently powerful charge into the grenade, and with having a sufficient mass of metal to provide a lethal shower of fragments. These considerations suggest that the grenade should be redesigned to weigh in the vicinity of 18 ounces.

The results on shape were essentially negative. The four shapes included three which were equivalent in accuracy and consistency, and one (the sphere) which was significantly less accurate than the others. It is of interest to note that the sphere, the "cultural" shape (it resembles a baseball--a shape nearly everyone has had experience in throwing), showed up so poorly. The other three shapes resembled each other in one respect--each was longer than it was wide. Oblong objects fit the general contour of the hand better than do circular objects and, therefore, may be easier to control and better suited to the transmittal of force in this gross throwing task. It may be that this is the pertinent characteristic which determines which shape is best for heavy objects which are to be thrown any distance. Further study is needed on this point.

Size did not influence performance at any significant level. A larger range of sizes will be included in a future study.

It should be noted that the scoring was quite gross--each throw was recorded to the nearest yard. Greater scoring precision might yield interactions which were not obtained in this study. The next study will use a finer scale of measurement.

V.   RECOMMENDATIONS

1.   The present Army hand grenade should be redesigned as a lighter object, probably around 18 ounces, in order to give the best combination of accuracy and consistency in throwing.

2.   The shape of the present grenade should not be altered, pending further study.

3.   The size of the present grenade should not be altered, pending further study.

4.   Additional studies using greater scoring precision should be done in order to determine more accurate interactions of size, shape and weight.

TABLE 1

DESCRIPTION OF PHYSICAL CHARACTERISTICS
OF GRENADES BY GRENADE NUMBER

Grenade Number	Size (Diameter in inches)	Shape	Weight (in oz)
1	2 1/4	Sphere	12
2	2 1/4	Standard	12
3	2 1/4	Tear Drop	12
4	2 1/4	Potato Masher	12
5	2 1/4	Sphere	18
6	2 1/4	Standard	18
7	2 1/4	Tear Drop	18
8	2 1/4	Potato Masher	18
9	2 1/4	Sphere	24
10	2 1/4	Standard	24
11	2 1/4	Tear Drop	24
12	2 1/4	Potato Masher	24
13	2	Sphere	12
14	2	Standard	12
15	2	Tear Drop	12
16	2	Potato Masher	12
17	2	Sphere	18
18	2	Standard	18
19	2	Tear Drop	18
20	2	Potato Masher	18
21	2	Sphere	24
22	2	Standard	24
23	2	Tear Drop	24
24	2	Potato Masher	24
25	2 1/2	Sphere	12
26	2 1/2	Standard	12
27	2 1/2	Tear Drop	12
28	2 1/2	Potato Masher	12 (15)*
29	2 1/2	Sphere	18
30	2 1/2	Standard	18
31	2 1/2	Tear Drop	18
32	2 1/2	Potato Masher	18
33	2 1/2	Sphere	24
34	2 1/2	Standard	24
35	2 1/2	Tear Drop	24
36	2 1/2	Potato Masher	24

*All five reproductions of grenade #28 weighed 15 ounces instead of
the specified 12 ounces.

TABLE 2

MEANS AND AVERAGE DEVIATIONS
(OBTAINED TRIGONOMETRICALLY) FOR EACH GRENADE

Grenade Number	Mean Error (yds)	Average Deviation (yds)
1	1.2	1.0
2	1.3	1.7
3	1.1	2.1
4	1.5	2.4
5	2.6	1.5
6	2.2	1.6
7	2.1	1.3
8	1.5	1.9
9	2.9	2.3
10	2.6	2.2
11	2.6	2.3
12	2.5	1.8
13	0.9	1.9
14	1.1	1.9
15	0.6	2.0
16	0.7	1.9
17	2.3	1.8
18	1.8	1.8
19	1.8	2.1
20	1.8	1.8
21	3.6	2.1
22	2.3	1.5
23	2.5	1.8
24	3.0	1.8
25	1.3	1.6
26	0.8	1.8
27	1.1	2.2
28	1.4	1.7
29	1.9	1.5
30	1.8	1.6
31	1.6	1.6
32	1.9	1.4
33	3.2	2.1
34	2.5	2.2
35	2.9	2.1
36	2.6	1.7

The Mean error is the radial distance from the Mean point of contact to the bull's-eye for all throws of each grenade. The Average deviation is the variability of these throws around the Mean point of contact.

TABLE 3

ANALYSES OF VARIANCE OF MEAN ERROR SCORES AND AVERAGE DEVIATIONS

Accuracy (Radial (Trig) Error)

Source of Variation	Ex^2	df	F
Shape (Sh)	0.97	3	4.48*
Size (S)	0.13	2	1.04
Weight (W)	17.01	2	11.80**
Sh x S	0.29	6	0.666
Sh x W	0.59	6	1.36
S x W	0.57	4	1.98
Remainder	0.86	12	
Total	20.42	35	

*Significant at 5% level.
**Significant at 1% level.

Consistency (Average Deviations)

Source of Variation	Ex^2	df	F
Shape (Sh)	0.17	3	0.94
Size (S)	0.04	2	0.33
Weight (W)	0.67	2	5.57*
Sh x S	0.45	6	1.23
Sh x W	0.74	6	2.02
S x W	0.54	4	2.21
Remainder	0.73	12	
Total	3.34	35	

*Significant at 5% level.

Bartlett's tests for the dimensions associated with the significant "F's" established homogeneity of variance.

TABLE 4

TEST OF SIGNIFICANCE FOR DIFFERENCES BETWEEN MEANS
ON VARIABLES WHICH YIELDED SIGNIFICANT F's

Mean Error (yds)	"t" Tests
Accuracy (Radial Trig Error)	
Weight:	
12 ounce = 1.08	t_{12-18} = 7.854**
18 ounce = 1.94	t_{12-24} = 15.433**
24 ounce = 2.77	t_{18-24} = 7.758**
	(1% = 2.819)
Shape:	
Sphere (SP) = 2.21	t_{SP-ST} = 3.083**
Standard (ST) = 1.82	t_{SP-TD} = 3.162**
Tear Drop (TD) = 1.81	t_{SP-PM} = 2.609*
Potato Masher (PM) = 1.88	t_{ST-TD} = 0.079
	t_{ST-PM} = 0.474
	t_{TD-PM} = 0.554
	(1% = 2.921)
	(5% = 2.120)
Consistency (Average Deviations)	
Weight:	
12 ounce = 1.85	t_{12-18} = 1.876
18 ounce = 1.66	t_{12-24} = 1.382
24 ounce = 1.99	t_{18-24} = 3.258**
	(1% = 2.819)

* Significant at 5% level.
**Significant at 1% level.
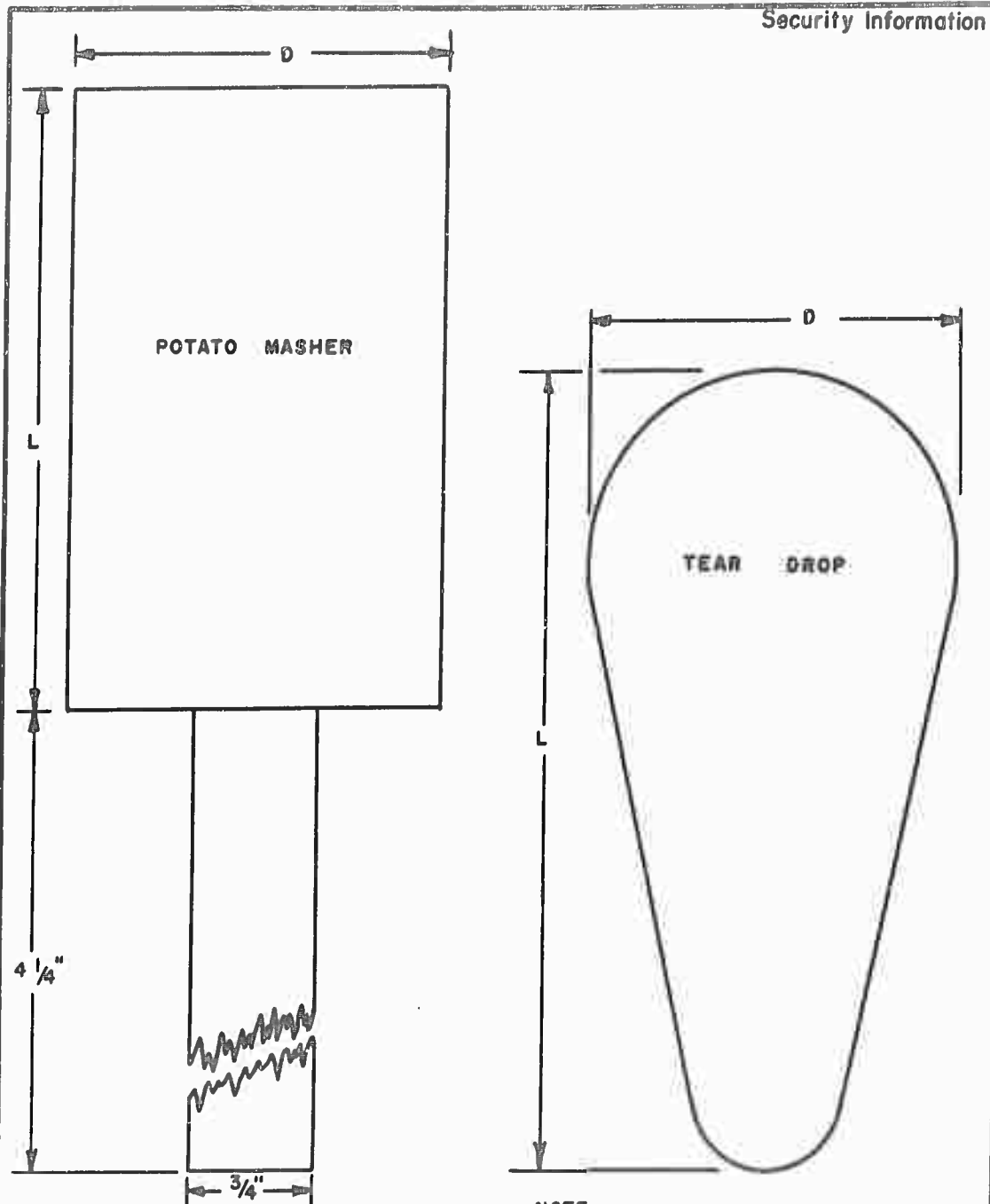
POTATO MASHER

TEAR DROP

NOTE:

D = 2", 2 1/4", OR 2 1/2"

D/L = 0.6 (APPROXIMATELY)

FIG.I – NOMENCLATURE AND CHARACTERISTICS OF

GRENADE TYPES STUDIED. WEIGHTS FOR ALL

GRENADES ARE 12-18-& 24 OUNCES.

SPHERE

D

STANDARD

D

L
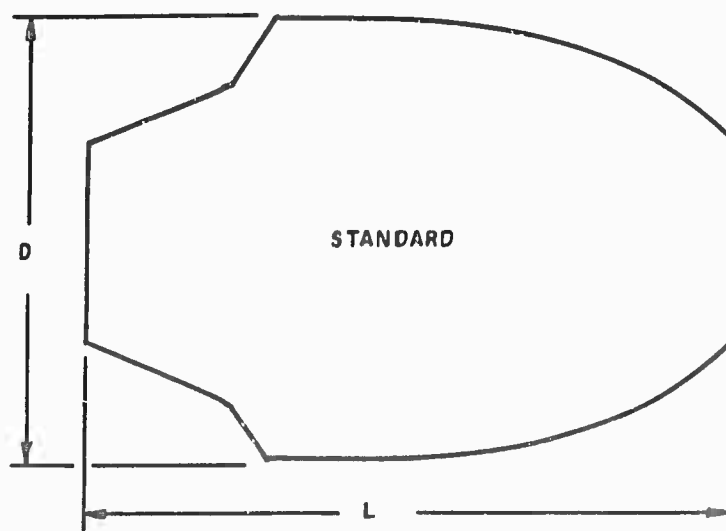
NOTE:
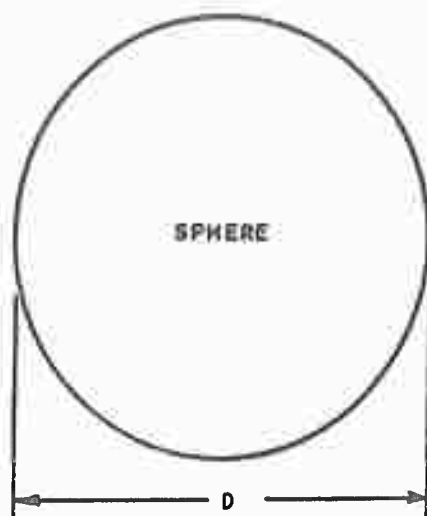D= 2", 2$\frac{1}{4}$" OR 2$\frac{1}{2}$"
D/L = 0.6 (APPROXIMATELY)

FIG. 2— NOMENCLATURE AND CHARACTERISTICS OF GRENADE
TYPES STUDIED. WEIGHTS FOR ALL GRENADES ARE
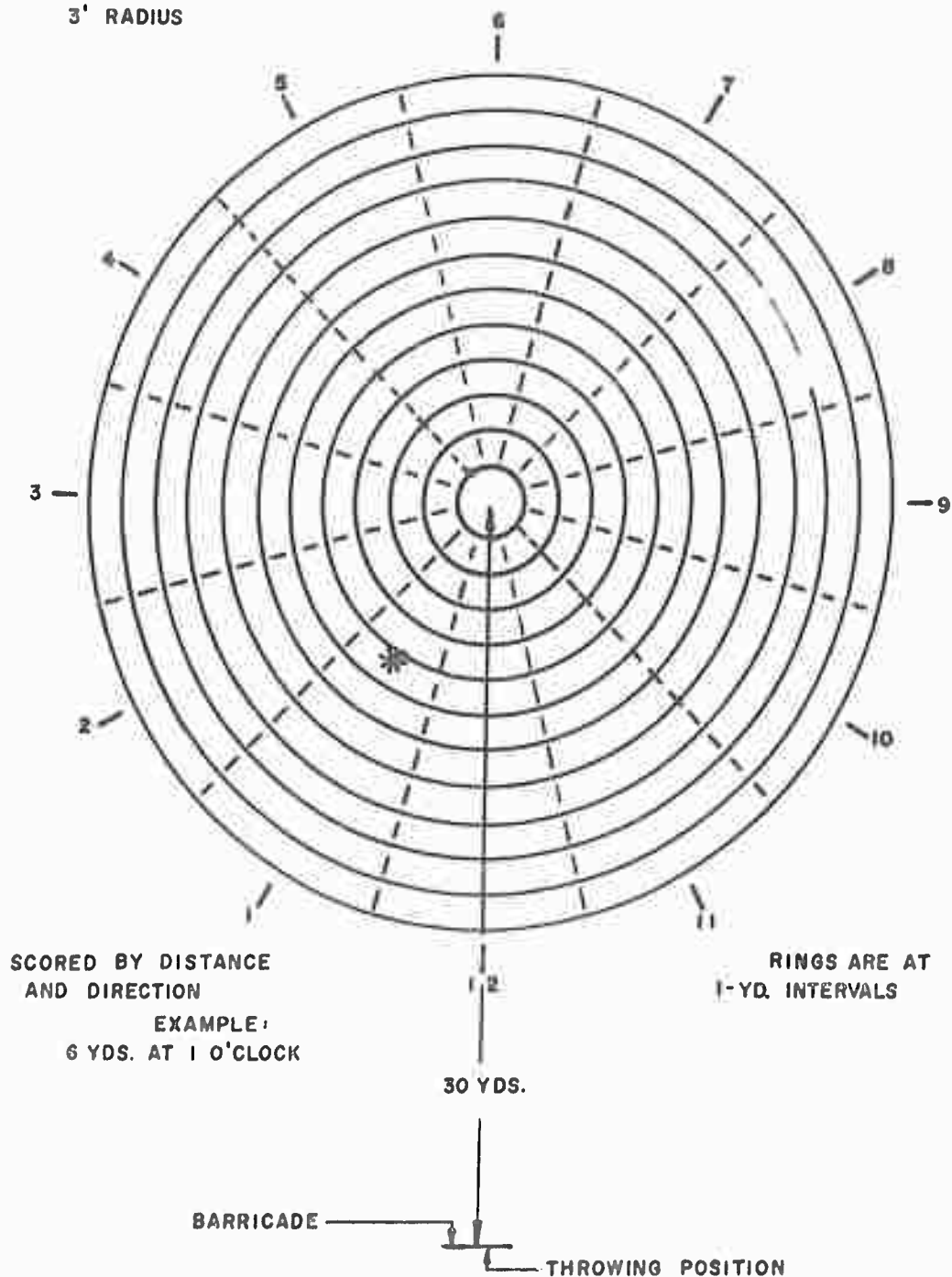12-18- & 24 OUNCES

TARGET CENTER
3' RADIUS

SCORED BY DISTANCE
AND DIRECTION
EXAMPLE:
6 YDS. AT 1 O'CLOCK

RINGS ARE AT
1-YD. INTERVALS

30 YDS.

BARRICADE —————
————THROWING POSITION

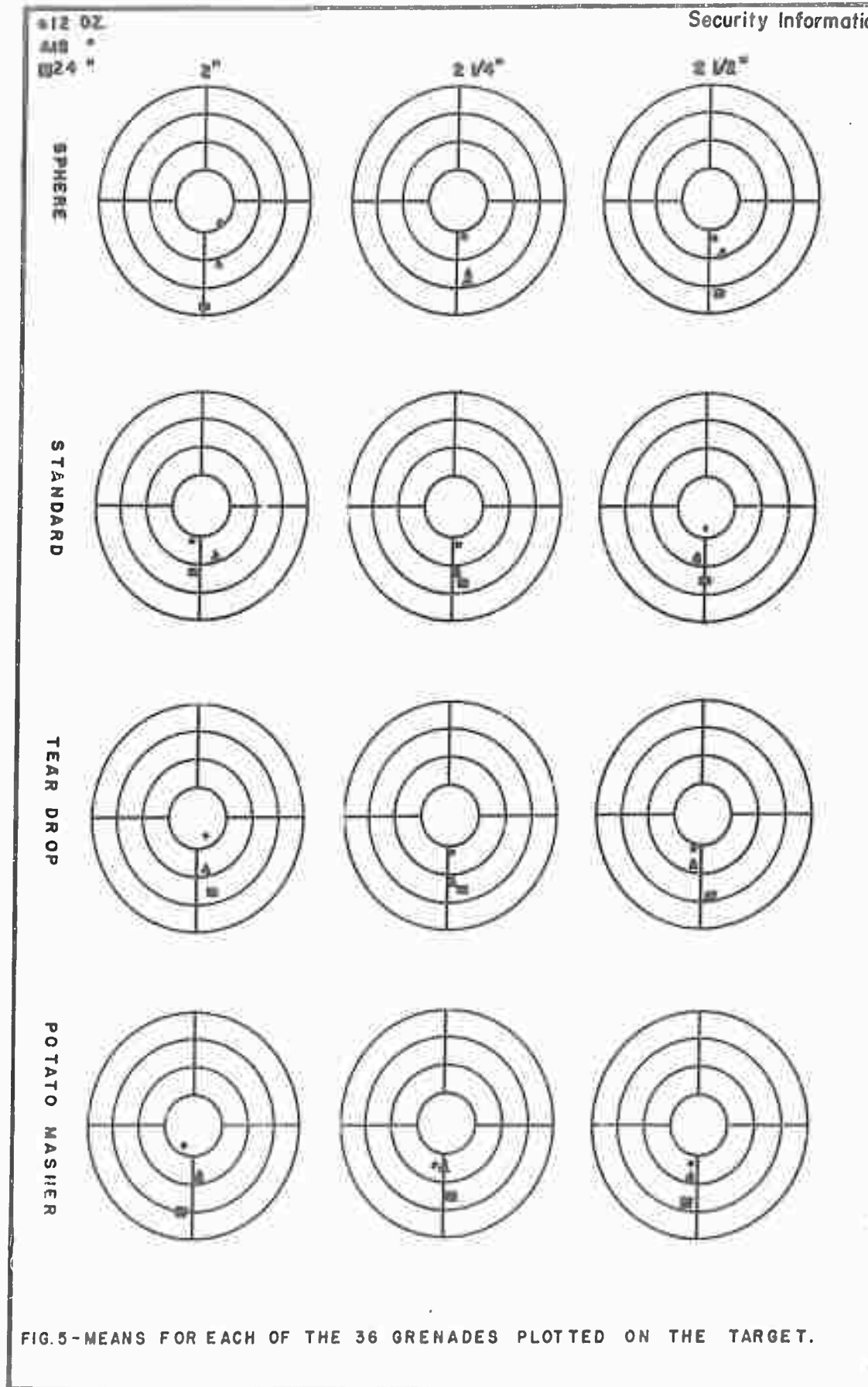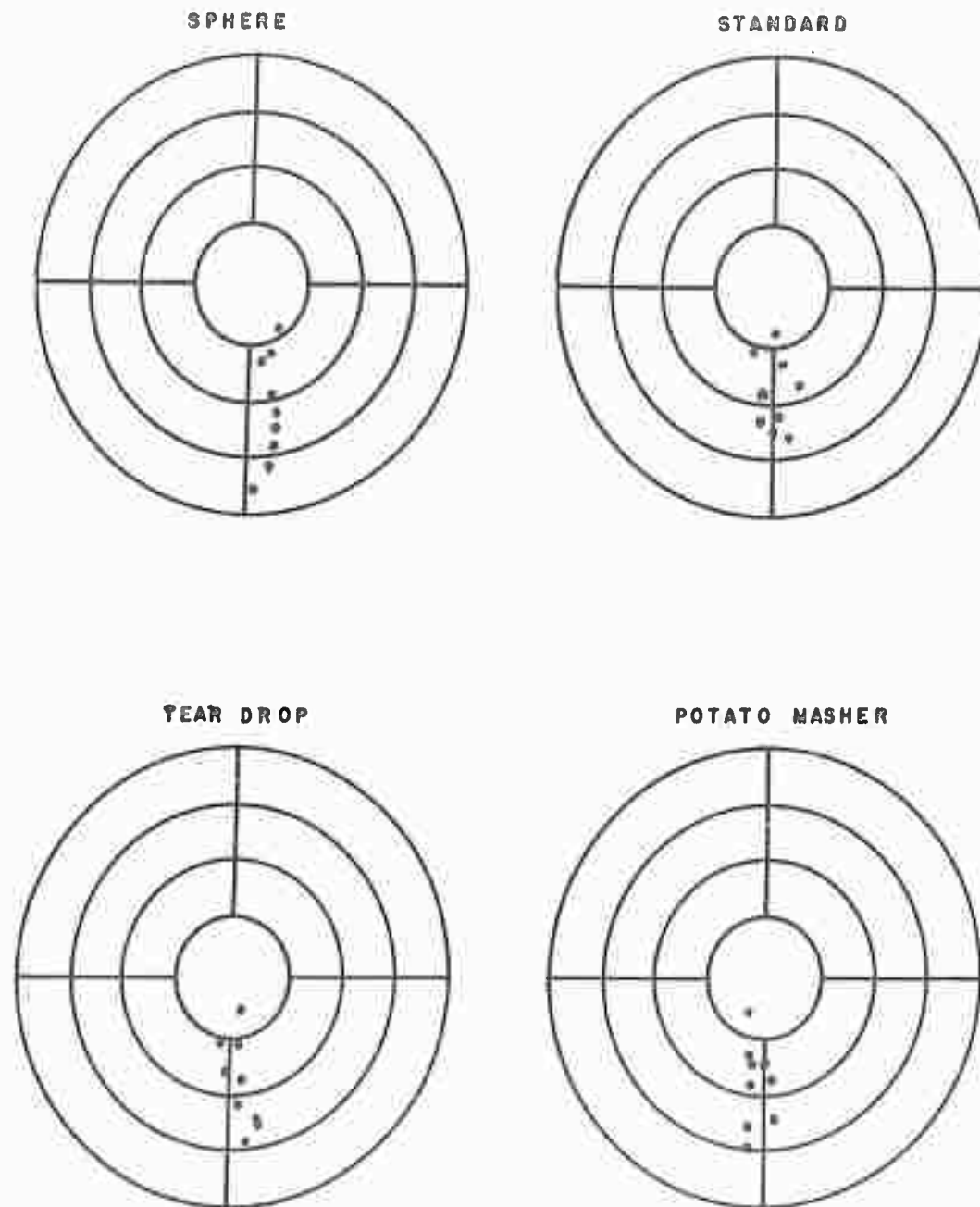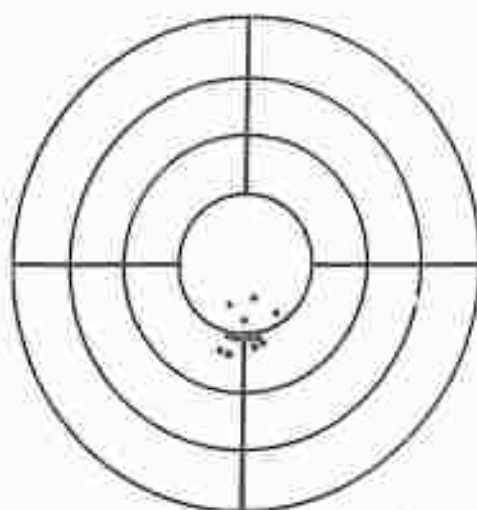FIG. 3— LAYOUT OF THE TARGET AREA AND METHODS OF SCORING

FOR HANDGRENADE THROWING.
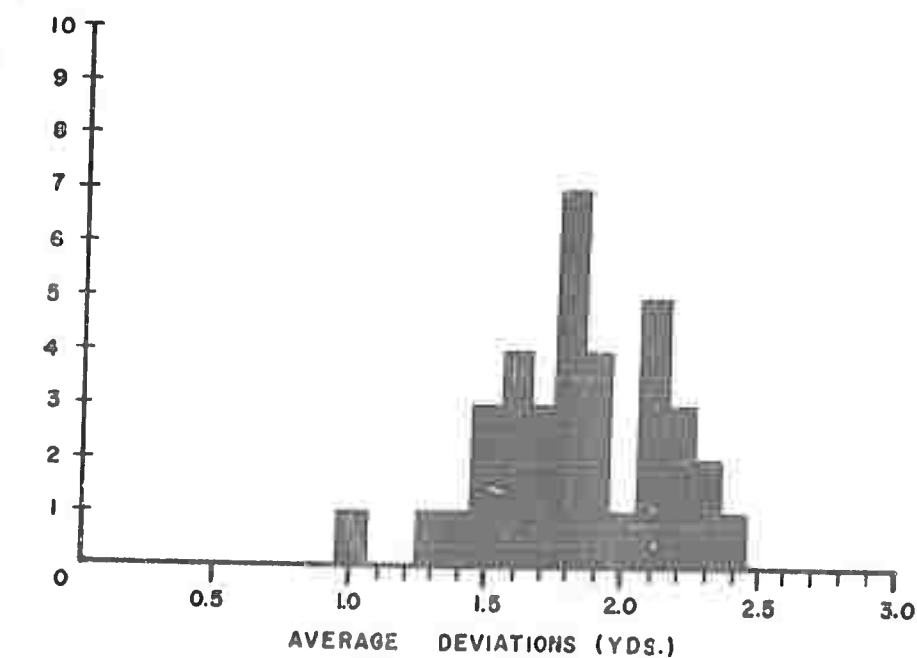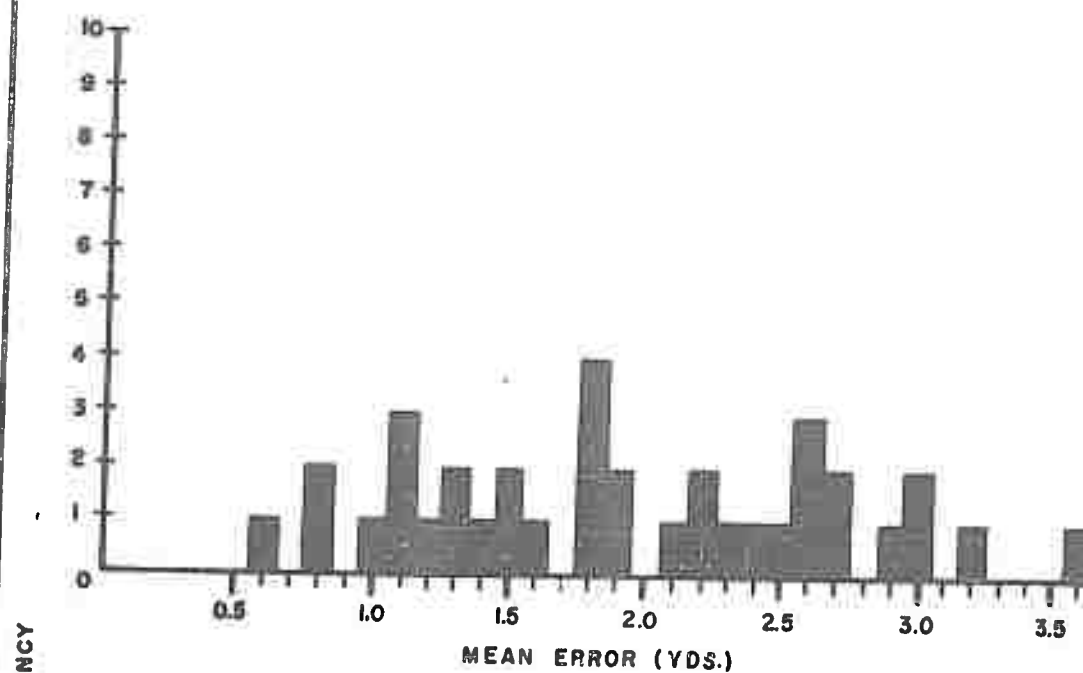
FIG. 4— FREQUENCY DISTRIBUTIONS OF MEAN ERROR SCORES

AND AVERAGE DEVIATIONS

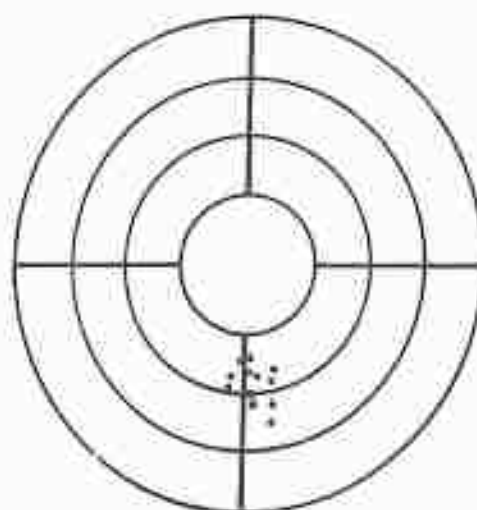FIG. 5 - MEANS FOR EACH OF THE 36 GRENADES PLOTTED ON THE TARGET.

FIG.6- MEANS FOR EACH OF THE 36 GRENADES IDENTIFIED BY
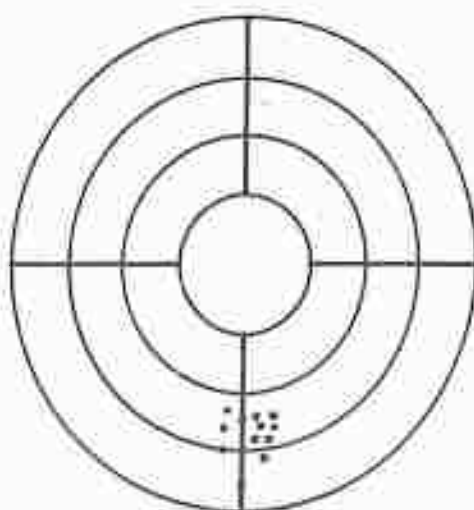SHAPE ONLY PLOTTED ON THE TARGET.

12 OZ.

18 OZ.

24 OZ.

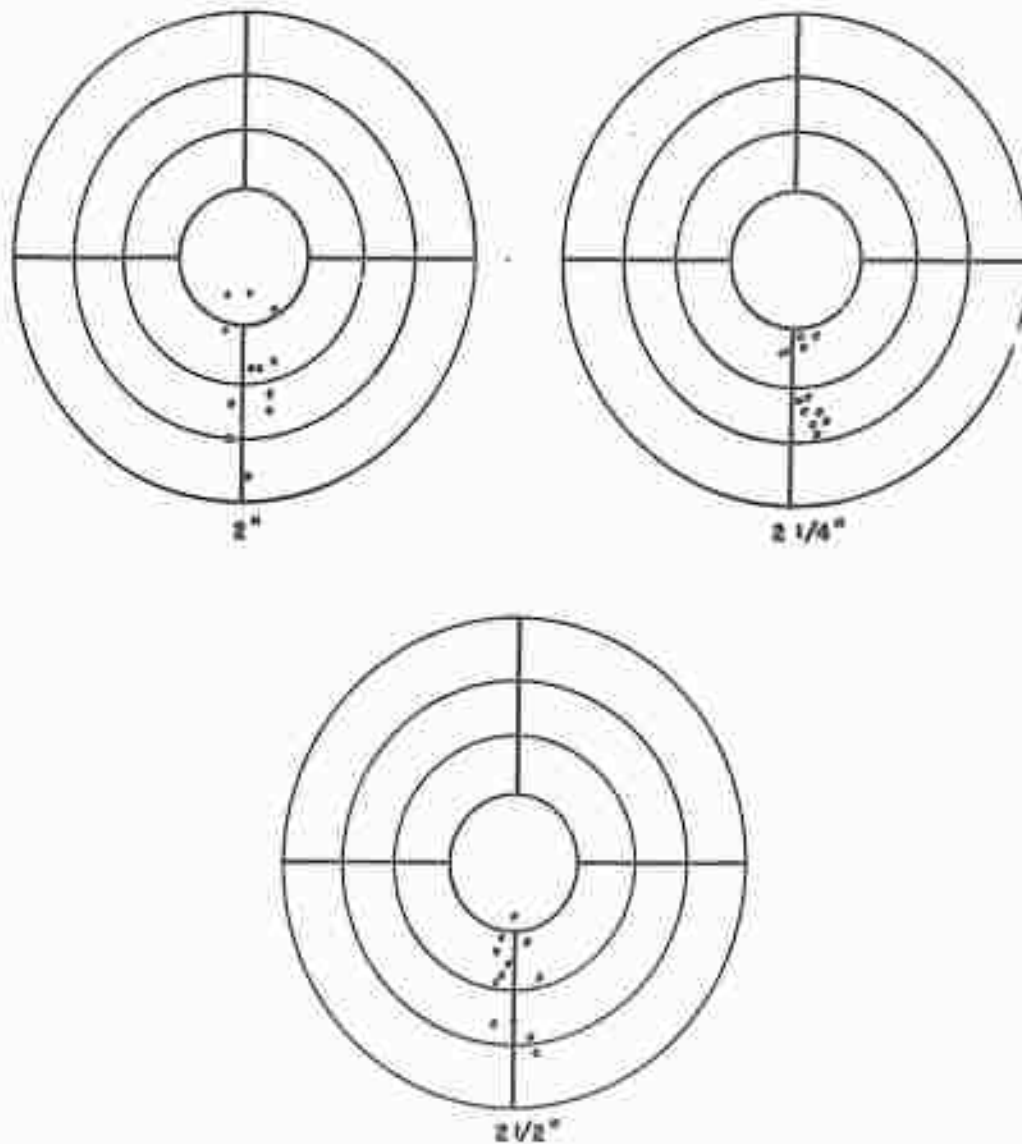FIG.7- MEANS FOR EACH OF THE 36 GRENADES IDENTIFIED BY WEIGHT ONLY PLOTTED ON THE TARGET AREA.

FIG. 8.- MEANS FOR EACH OF THE 36 GRENADES IDENTIFIED

BY SIZE ONLY PLOTTED ON THE TARGET.

APPENDIX I

TRIGONOMETRIC TRANSFORMATIONS OF SCORES

Each throw was scored as a distance and a direction from the bull's-eye. These two scores described a point on the target area which could also be specified by a system of x and y coordinates similar to that used on maps. For this coordinate system, the y axis was a line drawn from the subject through the bull's-eye, and the x axis was perpendicular to the y axis, intersecting it at the bull's-eye. The target center was the zero point for both axes, with positive and negative values for x being right and left, respectively, and positive and negative values for y being beyond and short, respectively, from the bull's-eye.

The x value for a single throw was found by a projection of the point of contact on the x axis using the equation, x = r cos. alpha, where x is the projection on the x axis, r is the distance from the point where the grenade landed to the target center, and alpha is the angle between the positive arm of the x axis and the line connecting the point of contact with the target center. The y value for a single throw was obtained by the same procedure, using the equation, y = r sin. alpha. The mean x value for five throws of one grenade type, thrown by one individual, was determined with the positive and negative signs of the projections considered. The mean y value was found in the same fashion.

A sample set of five scores and their trigonometric transformations are presented in the following table.

TABLE

Throw	Radial Score		Trigonometric Score			
	Distance (yards)	Direction (degrees)	Cosine x (yards)		Sine y (yards)	
1	3	30	0.5	-1.5	0.866	-2.6
2	3	60	0.866	-2.6	0.5	-1.5
3	3	0	0	0	1.0	-3.0
4	2	180	0	0	1.0	+2.0
5	2	270	1.0	+2	0	0
				Sum = -2.1		Sum = -5.1
				Mean = -0.42		Mean = -1.02

The intersection of the projections of the mean x and mean y values determine a point which is the mean point of contact for that group of five throws. A mean was obtained on each grenade for each of the subjects. The same method was used to find the mean of the entire group of subjects for each type of grenade. By this technique, a set of 36 means was found, one for each grenade, each mean having an N of 115 scores.

Variance associated with a specific grenade was obtained by a similar method; An x, y coordinate system was located with the center at the previously determined mean for the group of scores for one grenade. The x axis was parallel to the previous axis, but was displaced by a distance k, where k = mean x. The y axis was parallel to the previously axis, but displaced a distance h, where h = mean y. The coordinate values for each of the points on the new coordinate system were found by the transformation equations: $x' = x - k$ and $y' = y - h$, where the sign of each of the values was considered.

From the resulting values, x' and y' for each point, a radial distance from the trigonometric mean, $R' = \sqrt{(x')^2 + (y')^2}$, was found. The twenty-three resulting radial distances were the radial deviations of the twenty-three points from the mean of the scatter plot. A mean of these deviations was calculated. This mean was the average deviation of the points of the scatter plot around the trigonometric mean of the distribution. An average deviation for each of the 36 grenades was calculated in this fashion.

The trigonometric calculation of the average deviation associated with the previously presented sample set of five scores is shown in the following table. In this sample, k = -0.42 yards and h = -1.02 yards.
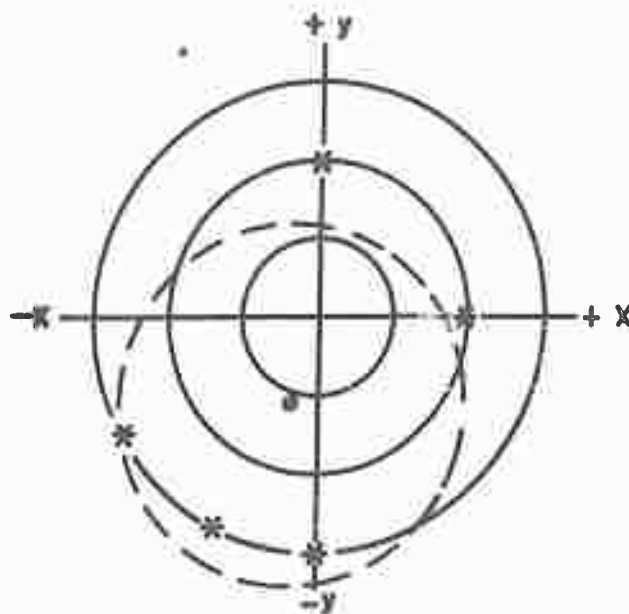
TABLE

Throw	Trigonometric Deviations (in yards)		
	x' (x - k)	y' (y - h)	$R' \left(\sqrt{(x')^2 + (y')^2} \right)$
1	-1.08	-1.58	1.90
2	-2.18	-0.42	2.22
3	+0.42	-1.98	2.01
4	+0.42	+3.02	3.04
5	+2.42	+1.02	2.62
			Sum = 11.79
		Average Deviation =	2.36

A graphic plot of the scores used in this illustration of the method is shown in the following figure. The asterisks represent the point of contact of each individual throw. The large dot represents the trigonometric mean. The dashed circle represents the average deviation.